which sections can be skipped.) Most chapters finish with a summary, and there is an overview of the book as a whole at the end.

Finally, a hint for impatient readers, keen to get into the quantum mechanics: start at chapter 5, and follow the arrows from there.

THE STOCK PHILOSOPHICAL DEBATES ABOUT TIME

The philosophy of time has a long history, and is unusual even by philosophical standards for the durability of some of its main concerns. In a modern translation much of Saint Augustine's work on time would pass for twentieth-century philosophy. Augustine's concerns are often exactly those of modern philosophers. He is puzzled about the nature of the distinctions between the past, the present, and the future, and about the fact that the past and the future seem unreal: the past has ceased to exist, and the future doesn't yet exist. And he is concerned about the nature and status of the apparent flow of time.

These two problems—the first the status of the past-present-future distinction, and the related concern about the existence of the past and the future, and the second the issue of the flow of time—remain the focus of much work in the philosophy of time. As I noted earlier, philosophers tend to divide into two camps. On one side there are those who regard the passage of time as an objective feature of reality, and interpret the present moment as the marker or leading edge of this advance. Some members of this camp give the present ontological priority, as well, sharing Augustine's view that the past and the future are unreal. Others take the view that the past is real in a way that the future is not, so that the present consists in something like the coming into being of determinate reality.

Philosophers in the opposing camp regard the present as a subjective notion, often claiming that *now* is dependent on one's viewpoint in much the same way that *here* is. Just as "here" means roughly "this place," so "now" means roughly "this time," and in either case what is picked out depends where the speaker stands. On this view there is no more an objective division of the world into the past, the present, and the future than there is an objective division of a region of space into here and there. Not surprisingly, then, supporters of this view deny that there is any ontological difference—any difference concerning simply *existence*—between the past, the present, and the future.

Often this is called the *block universe view,* the point being that it regards reality as a single entity of which time is an ingredient, rather than as a changeable entity set *in* time. The block metaphor sometimes leads to confusion, however. In an attempt to highlight the contrast with the dynamic

character of the "moving present" view of time, people sometimes say that the block universe is *static*. This is rather misleading, however, as it suggests that there is a time frame in which the four-dimensional block universe stays the same. There isn't, of course. Time is supposed to be included in the block, so it is just as wrong to call it static as it is to call it dynamic or changeable. It isn't any of these things, because it isn't the right sort of entity—it isn't an entity *in* time, in other words.

Defenders of the block universe view deny that there is an objective present, and usually also deny that there is any objective flow of time. Indeed, perhaps the strongest reason for denying the objectivity of the present is that it is so difficult to make sense of the notion of an objective flow or passage of time. Why? Well, the stock objection is that if it made sense to say that time flows then it would make sense to ask how fast it flows, which doesn't seem to be a sensible question. Some people reply that time flows at one second per second, but even if we could live with the lack of other possibilities, this answer misses the more basic aspect of the objection. A rate of seconds per second is not a rate at all in physical terms. It is a dimensionless quantity, rather than a rate of any sort. (We might just as well say that the ratio of the circumference of a circle to its diameter flows at π seconds per second!)

A rarer but even more forceful objection is the following. If time flowed, then—as with any flow—it would only make sense to assign that flow a *direction* with respect to a choice as to what is to count as the positive direction of time. In saying that the sun moves from east to west or that the hands of a clock move clockwise, we take for granted the usual convention that the positive time axis lies toward what we call the future. But in the absence of some objective grounding for this convention, there isn't an objective fact as to which way the sun or the hands of the clock are "really" moving. Of course, proponents of the view that there is an objective flow of time might see it as an advantage of their view that it does provide an objective basis for the usual choice of temporal coordinate. The problem is that until we have such an objective basis we don't have an objective sense in which time is flowing one way rather than the other. In other words, not only does it not seem to make sense to speak of an objective *rate* of flow of time; it also doesn't make sense to speak of an objective *direction* of flow of time.

These problems in making sense of an objective flow of time spill over on the attempt to make sense of an objective present. For example, if the present is said to be the "edge" at which reality becomes concrete, at which the indeterminacy of the future gives way to the determinacy of the past, then the argument just given suggests that there isn't an objective sense in which reality is growing rather than shrinking.

These objections are all of a philosophical character, not especially dependent on physics. A new objection to the view that there is an objective present arises from Einstein's theory of special relativity. The objection is most forceful if we follow Augustine in accepting that only the present moment is real. For then if we want to inquire what reality includes, apart from our immediate surroundings, we need to think about what is *now* happening elsewhere. However, Einstein's theory tells us that there is no such thing as objective simultaneity between spatially separated events. Apparent simultaneity differs from observer to observer, depending on their state of motion, and there is no such thing as an objectively right answer. So the combination of Augustine and Einstein seems to give us the view that reality too is a perspective-dependent matter. The distinctive feature of the Augustinian view—the claim that the content of the present moment is an objective feature of the world—seems to have been lost.

Augustine's own reasons for believing in the objectivity of the present—indeed, the nonreality of everything else—seem to have been at least partly linguistic. That is, he was moved by the fact that we say such things as "There are no dinosaurs—they no longer exist" and "There is no cure for the common cold—it doesn't yet exist." By extrapolation, it seems equally appropriate to say that there is no past, for it no longer exists; and that there is no future, for it does not yet exist. However, a defender of the block universe view will say that in according these intuitions the significance he gives them, Augustine is misled by the tense structure of ordinary language. In effect, he fails to notice that "Dinosaurs do not exist" means "Dinosaurs do not exist *now*." As a result, he fails to see that the basic notion of existence or reality is not the one that dinosaurs are here being said to lack—viz., existence *now*—but what we might term existence *somewhen*. Again the spatial analogy seems helpful: we can talk about existence in a spatially localized way, saying, for example, that icebergs don't exist here in Sydney; but in this case it is clear that the basic notion of existence is the unqualified one—the one that we would describe as existence *somewhere*, if language required us to put in a spatial qualification. We are misled in the temporal case because the simplest grammatical form actually includes a temporal qualification.

So it is doubtful whether Augustine's view can be defended on linguistic grounds. In practice, the most influential argument in favor of the objective present and objective flow of time rests on an appeal to psychology—to our own experience of time. It seems to us as if time flows, the argument runs, and surely the most reasonable explanation of this is that there is some genuine movement of time which we experience, or in which we partake.

Arguments of this kind need to be treated with caution, however. After all, how would things seem if it time didn't flow? If we suppose for the moment

that there is an objective flow of time, we seem to be able to imagine a world which would be just like ours, except that it would be a four-dimensional block universe rather then a three-dimensional dynamic one. It is easy to see how to map events-at-times in the dynamic universe onto events-at-temporal-locations in the block universe. Among other things, our individual mental states get mapped over, moment by moment. But then surely our copies in the block universe would have the same experiences that we do—in which case they are not distinctive of a dynamic universe after all. Things would seem this way, even if we ourselves were elements of a block universe.

Proponents of the block universe view thus argue that in the case of the apparent flow of time, like that of the apparent objectivity of the present, it is important to draw a distinction between how things *seem* and how they actually are. Roughly speaking, what we need to do is to explain why things *seem* this way, without assuming that the "seeming" corresponds directly to anything in reality. Explanations of this kind are quite common in philosophy. Their general strategy is to try to identify some characteristic of the standpoint from which we "see" the appearance in question, such that the nature of the appearance can be explained in terms of this characteristic of the viewpoint. (There are lots of commonplace examples of this kind of thing. Rose-tinted spectacles explain why the world seems warm and friendly to those who wear them.)[4]

One of my projects in this book is to try to extend these insights about the consequences of the temporal perspective from which we view the world. We are interested in this partly for its bearing on the attempt to explain the arrow of time—existing attempts often go wrong because they fail to notice the influence of this perspective on ordinary ways of thinking—but also for its general philosophical interest. In this respect, as I said earlier, the book is an attempt to further the project of philosophical writers such as Williams, Smart, and Mellor.

From now on I shall simply take for granted the main tenets of the block universe view. In particular, I'll assume that the present has no special objective status, instead being perspectival in the way that the notion of *here* is. And I'll take it for granted that there is no objective flow of time. These assumptions will operate mainly in a negative way. I shall not explore the suggestion that flow gives direction to time, for example, because I shall be taking for granted that there is no such thing as flow.

In making these assumptions I don't mean to imply that I take the arguments for the block universe view sketched above to be conclusive. I do think that it is a very powerful case, by philosophical standards. However, the aim of the book is to explore the consequences of the block universe view in physics and philosophy, not to conduct its definitive defense. My

impression is that these consequences give us new reasons to favor the view over its Augustinian rival, but others might take the point in reverse, finding here new grounds for the claim that the block universe leaves out something essential about time. Either way, all that matters to begin with is that the block universe view is not already so implausible that it would a waste of time to seek to extend it in this way, and this at least is not in doubt.

THE ARROWS OF TIME

Our main concern is with the asymmetry of time, but what does this mean? The terminology suggests that the issue concerns the asymmetry *of time itself,* but this turns out not to be so. To start with, then, we need to distinguish the issue of the asymmetry *of* time from that of the asymmetry of things *in* time. The easiest way to do this is to use a simple spatial analogy.

Imagine a long narrow table, set for a meal. The contents of the table might vary from end to end. There might be nonvegetarian food at one end and vegetarian at the other, for example; there might be steak knives at one end but not at the other; all the forks might be arranged so as to point to the same end of the table; and so on. This would constitute asymmetry *on* the table. Alternatively, or as well, the table itself might vary from end to end. It might be wider or thicker at one end than the other, for example, or even bounded in one direction but infinite in the other. (This might be a meal on Judgment Day, for example, with limited seating at the nonvegetarian end.) These things would be asymmetries *of* the table—asymmetries of the table itself, rather than its contents.

There seems to be an analogous distinction in the case of time. Time itself might be asymmetric in various ways. Most obviously, it might be bounded in one direction but not in the other. There might be an earliest time but no latest time. There are other possibilities: as long as we think of time as a kind of extended "stuff," there will be various ways in which the characteristics of this stuff might vary from end to end. More contentiously, if sense could be made of the notion of the flow of time, then that too might provide a sense in which time itself had an intrinsic direction or asymmetry. (However, supporters of the objective present/objective flow view are likely to be unhappy with this use of a spatial metaphor to characterize the distinction between the asymmetry of time and that of things in time.)

Independently of the issue as to whether time itself is symmetric from end to end, there is an issue about whether the physical contents of time are symmetric along its axis. This is analogous to the question as to whether the contents of the table are symmetric from end to end. It turns out that the interesting questions about temporal asymmetry are very largely of this kind.

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There are various respects in which the contents of the block universe appear to be arranged asymmetrically with respect to the temporal axis. For example, many common physical processes seem to exhibit a very marked temporal preference, occurring in one temporal orientation but not the other. This is why the events depicted in reversed films often seem bizarre. In the real world, buildings may collapse into rubble, for example, but rubble does not "uncollapse" to form a building—even though, as it happens, the latter process is no less consistent than the former with the laws of mechanics. (It is this last fact that makes the asymmetry so puzzling—more on this in a moment.)

As we shall see in the following chapters, there are a number of apparently distinct ways in which the world we inhabit seems asymmetric in time. One of the tasks of an account of temporal asymmetry is thus a kind of taxonomic one: that of cataloging the different asymmetries (or "arrows," as they have come to be called), and sorting out their family relationships. Physicists in particular have been interested in the question as to whether there is a single "master arrow," from which all the others are in some sense derived. As we shall see, the leading candidate for this position has been the so-called arrow of thermodynamics. This is the asymmetry embodied in the second law of thermodynamics, which says roughly that the entropy of an isolated physical system never decreases.

As a gentle introduction to the kind of reasoning on which much of the book depends, note that this formulation of the second law assumes a choice of temporal orientation. It assumes that we are taking the "positive" temporal direction to be that of what we ordinarily call the future. There is nothing to stop us taking the positive axis to lie in the opposite direction, however, in which case the second law would need to be stated as the principle that the entropy of an isolated system never *increases.* The lesson is that the objective asymmetry consists in the presence of a unidirectional gradient in the entropy curve of, apparently, all isolated physical systems. Each such system exhibits such a gradient, and all the gradients slope in the same temporal direction. But it is not an objective matter whether the gradients *really* go up or go down, for this simply depends on an arbitrary choice of temporal orientation. They don't *really* go either way, from an atemporal viewpoint.

THE PUZZLE OF ORIGINS

One of the problems of temporal asymmetry is thus to characterize the various temporal arrows—asymmetries of things *in* time—and to explain how they relate to one another. Let's call this the *taxonomy problem.* The second problem—call it the *genealogy problem*—is to explain why there is *any*

significant asymmetry of things in time, given that the fundamental laws of physics appear to be (almost) symmetric with respect to time. Roughly, this symmetry amounts to the principle that if a given physical process is permitted by physical laws, so too is the reverse process—what we would see if a film of the original process were shown in reverse. With one tiny exception—more on this in a moment—modern physical theories appear to respect this principle. This means that insofar as our taxonomy of temporal arrows reveals significant asymmetries—significant cases in which the world shows a preference for one temporal orientation of a physical process over the other, for example—it is puzzling how these asymmetries could be explained in terms of the available physical theories. How are we going to explain why buildings collapse into rubble but rubble does not "uncollapse" into buildings, for example, if both processes are equally consistent with the laws of mechanics? We seem to be trying to pull a square rabbit from a round hat!

As I noted, however, there seems to be one little exception to the principle that the basic laws of physics are time-symmetric. This exception, first discovered in 1964, concerns the behavior of a particle called the neutral kaon. To a very tiny extent, the behavior of the neutral kaon appears to distinguish past and future—an effect which remains deeply mysterious.[5] Tiny though it is, could this effect perhaps have something to do with the familiar large-scale asymmetries (such as the tendency of buildings to collapse but not "uncollapse")? At present, it is difficult to offer a convincing answer to this question, one way or the other. The best strategy is to set the case of the kaon to one side, and to study the more familiar arrows of time in physics as if there were no exceptions to the principle that the underlying laws are time-symmetric. This way we can find out where the puzzles really lie—and where, if at all, the kaon might have a role to play.[6]

Physicists and philosophers have long been puzzled by the genealogy problem. The most famous attempt to provide at least a partial solution dates from the second half of the nineteenth century, when Boltzmann claimed to have derived the second law of thermodynamics for the case of gases from a statistical treatment within the symmetrical framework of Newtonian mechanics. As we shall see in the next chapter, however, Boltzmann's critics soon pointed out that he had relied on a temporally asymmetric assumption (the so-called *stoßzahlansatz,* or "assumption of molecular chaos"). Boltzmann's argument thus provides an early example of what has proved a common and beguiling fallacy. In search of an explanation for the observed temporal asymmetries—for the observed difference between the past and the future, in effect—people unwittingly apply different standards with respect to the two temporal directions. The result is that the asymmetry they get out is just the asymmetry they put in. Far from being solved, the problems of

temporal asymmetry are obscured and deferred—the lump in the carpet is simply shifted from one place to another. In the course of the book we shall encounter several examples of this kind of mistake.

The reason the mistake is so prevalent is not (of course) that the physicists and philosophers who have thought about these problems are victims of some peculiar intellectual deficit. It is simply that temporal asymmetry is so deeply ingrained in our ways of thinking about the world that it is very difficult indeed to spot these asymmetric presuppositions. Yet this is what we need to do, if we are to disentangle the various threads in the problem of temporal asymmetry, and in particular to distinguish those threads that genuinely lie in the world from those that merely reflect our own viewpoint. In order to explain temporal asymmetry it is necessary to shake off its constraints on our ordinary ways of thinking—to stand in thought at a point outside of time, and thence to regard the world in atemporal terms. This book is a kind of self-help manual for those who would make this Archimedean journey.

To put the project in perspective, let us reflect again on the history of science, or natural philosophy more generally. In hindsight it is easy to see that our view of the world has often unwittingly embodied the peculiarities of our own standpoint. As I noted earlier, some of the most dramatic episodes in the history of science are associated with the unmasking of distortions of this kind. I mentioned Copernicus and Darwin. Another striking example is the conceptual advance that led to Newton's first law of motion. This advance was Galileo's appreciation that the friction-dominated world of ordinary mechanical experience was not the natural and universal condition it had been taken to be. Left to its own devices, a moving body would move forever.

In the same historical period we find a parallel concern with the philosophical aspects of the project of uncovering the anthropocentricities of our ordinary view of the world. We find an interest in what soon came to be called the distinction between primary and secondary qualities, and an appreciation that the proper concern of physics is with the former: that is, with those aspects of the world that are not the product of our own perceptual peculiarities.

Consider these remarks from Galileo himself, for example, in 1623:

> I feel myself impelled by the necessity, as soon as I conceive a piece of matter or corporeal substance, of conceiving that in its own nature it is bounded and figured in such and such a figure, that in relation to others it is large or small, that it is in this or that place, in this or that time, that it is in motion or remains at rest, that it touches or does not touch another body, that it is single, few, or many; in short by no imagination can a body be separated from

> such conditions; but that it must be white or red, bitter or sweet, sounding or mute, of a pleasant or unpleasant odour, I do not perceive my mind forced to acknowledge it necessarily accompanied by such conditions; so if the senses were not the escorts, perhaps the reason or the imagination by itself would never have arrived at them. Hence I think that these tastes, odours, colours, etc., on the side of the object in which they seem to exist, are nothing else than mere names, but hold their residence solely in the sensitive body; so that if the animal were removed, every such quality would be abolished and annihilated.[7]

Galileo is telling us that tastes, odors, colors, and the like are not part of the objective furniture of the world; normally, in thinking otherwise, we mistake a by-product of our viewpoint for an intrinsic feature of reality. In Galileo and later seventeenth-century writers, the move to identify and quarantine these secondary qualities is driven in part by the demands of physics; by the picture supplied by physics of what is objective in the world. This is not a fixed constraint, however. It changes as physics changes, and some of these changes themselves involve the recognition that some ingredient of the previously excepted physical world view is anthropocentric.

These examples suggest that anthropocentrism infects science by at least two different routes. In some cases the significant factor is that we happen to live in an exceptional part of the universe. We thus take as normal what is really a regional specialty: geocentric gravitational force, or friction, for example. In other cases the source is not so much in our *location* as in our *constitution.* We unwittingly project onto the world some of the idiosyncrasies of our own makeup, seeing the world in the colors of the in-built glass through which we view it. But the distinction between these sources is not always a sharp one, because our constitution is adapted to the peculiarities of our region.

It is natural to wonder whether modern physics is free of such distortions. Physicists would be happy to acknowledge that physics might uncover new locational cases. Large as it is, the known universe might turn out to be an unusual bit of something bigger.[8] The possibility of continuing constitutional distortions is rather harder to swallow, however. After all, it challenges the image physics holds of itself as an objective enterprise, an enterprise concerned with not with how things *seem* but with how they actually *are.* It is always painful for an academic enterprise to have to acknowledge that it might not have been living up to its own professed standards!

In the course of the book, however, I want to argue that in its treatment of time asymmetry, contemporary physics has failed to take account of distortions of just this constitutional sort—distortions which originate in the kind

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of entities we humans are, in one of our most fundamental aspects. If we see the historical process of detection and elimination of anthropocentrism as one of the adoption of progressively more detached standpoints for science, my claim is that physics has yet to achieve the standpoint required for an understanding of temporal asymmetry. In this case the required standpoint is an atemporal one, a point outside time, a point free of the distortions which stem from the fact that we are creatures in time—truly, then, a view from nowhen.